Friction Stir Welding

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In conventional fusion welding the edges of a seam are joined as solidified metal left in the wake of a little weld pool melted by a powerful heat source and moved along the seam. As the metal at the rear of the weld pool solidifies, different temperature changes produce different amounts of shrinkage or expansion at different locations. Metal elements attached to other elements undergoing a greater expansion or a lesser shrinkage may be pulled apart and may crack. Certain metals have a strong tendency to crack and on this account are difficult to weld.

But metals need not be melted to weld them. Any time metal surfaces are brought into contact at the atomic level, whether by melting or by mechanical force, they stick together in a natural weld. A century or so ago the most common type of weld, the forge weld of the blacksmith, was a solid state weld. Hammer blows produced large forces that broke up the surface oxides and squeezed the metal surfaces into intimate contact. The metal was heated to make it flow more easily, but it was not melted. A flux, perhaps sand, was added to the joint to make the surface oxides melt so that they could be squeezed out of the joint more easily. The joint surfaces were humped so that the weld would spread from a single contact and oxide would not be trapped.

But the blacksmith's solid-state process was not terribly sensitive to surface contamination. The fusion welding process, on the contrary is often very sensitive to contaminants, which can cause serious porosity and cracking, accompanied by substantially reduced strength. The blacksmith hardly had recourse to inert gas shielding, solvent washes and scraping of joint surfaces, white glove handling, reverse polarity cleaning, etc. Fabricators of the Space Shuttle external tank use these techniques routinely.

As fusion welding techniques become more capable, more difficult welding challenges are being posed. The lighter-stronger 2195 aluminum-lithium alloy specified for the new Space Shuttle lightweight tank is more difficult to weld than the old 2219 aluminum alloy. As weldability constraints can be relaxed, stronger and lighter alloys can be specified.

On this account in 1994, MSFC began to consider solid state welding processes and became very interested in the friction stir welding (FSW) process invented by The Welding Institute (TWI) in the United Kingdom in 1991. In 1995, MSFC set up the nucleus of a laboratory to develop the FSW process to meet the needs of the next generation of space vehicle fabricators. MSFC FSW laboratory welds made in quarter-in-thick 2195 aluminum-lithium alloy plate already exhibit strengths a bit higher than comparable fusion welds, and the FSW process has yet to be optimized.

In FSW a rotating pin is inserted into the joint between pieces to be welded and moved along the seam, stirring the metal together as it goes. The plastic flow generates heat, the temperature rises near the pin, and the metal flow stress goes down so the forces are much smaller than they would be in cold metal. To keep the metal in place, a shoulder bears down on the metal surface above the pin and a backing bar supports the back of the seam. The shoulder contributes plastic flow and heating of its own.

A major drawback to the FSW process is the large forces that must be applied to the plate. A much simplified analysis of the FSW plastic flow process predicts forces inversely proportional to the rotational speed of the pin tool and suggests that by going to high rotational speeds the loads can be greatly reduced. Preliminary empirical studies at the University of Texas at El Paso seem to corroborate this idea; however, MSFC found a falling off of weld strength at higher rotational speeds.

Therefore in conjunction with a design effort directed towards the fabrication of FSW tooling capable of producing full-size space vehicle hardware, and an associated effort to develop nondestructive evaluation techniques appropriate for inspecting the unique structure of an FSW weld, an effort towards undertanding and characterizing the flow of metal in FSW welding is also underway at MSFC to be followed by tool geometry and process parameter optimization studies.

If the loads can be sufficiently lowered while maintaining weld strength, the minimal debris, electrical, and thermal hazards of the FSW process make it a candidate for an in-space as well as a terrestrial welding process.

Thomas, W.M., et al.: Friction Stir Butt Welding, December 6, 1991. International patent application number PCT/GB92/02203 and GB patent application number 9125978.8.

Sponsor: Office of Space Flight

Biographical Sketch: Robert Ding is principal investigator for the Friction Stir Welding development effort. He is an aerospace engineer with the Materials and Processes Laboratory at MSFC. Ding holds an M.S. in engineering from the University of Tennessee as well as bachelor's degrees in welding engineering (Ohio State University) and biology (Bowling Green State University, Ohio).

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